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Voltage and Energy Utilization Enhancement In A Stand-Alone WECS

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ABSTRACT: In this study, a novel sinusoidal PWM switched AC/DC/AC converter interface scheme using real novel tri-loop voltage error tracking fuzzy logic controller (FLC), to stabilize the stand alone Wind Energy Conversion Scheme (WECS) using an induction generator. The proposed novel sinusoidal Pulse Width Modulator (SPWM) switched (AC/DC/AC) converter (diode rectifier and 6-pulse IGBT inverter) interface scheme serves as a combined voltage stabilization regulator and maximum wind energy utilization and enhancement compensator.

Index Terms: Wind Energy Conversion Scheme, Fuzzy Logic Controller, AC/DC/AC Interface, PWM inverter

I. INTRODUCTION

The demand for Electrical Energy and Fossil fuel has increased continuously during the last two or three decades with energy shortage, dwindling world fossil fuel and non-renewable natural resources. This has renewed interest in green Energy and Renewable/Alternative Wind, Photovoltaic, Fuel Cell, Bio-fuels and hybrid green energy schemes to supplement, complement and even replace fossil energy consumption in specific applications such as Transportation and Drive Systems. Extensive efforts in Energy Conservation, Demand Side Management and Efficient utilization, Loss Reduction can sustain the drive for LIVE-EARTH Renewal and Sustainability-Drive. Green House Gases, Water and Air Pollution and Rising Environmental Concerns are the motivating forces behind the Search for New Sustainable Energy. The traffic congestion problems have also grown and the increasing fuel cost did increase cost of living and acted as a Catalyst for New Technology Applications in Transportation Locomotive and Drive Sectors. The general view of the international oil industry regarding world oil reserves is even more alarming. The world oil market is expected to become a seller’s market as early as 2006 and at the latest by 2016. Temporarily, the balance of power will shift towards Organization of Petroleum Exporting Countries (OPEC), but even the Middle East production is expected to start falling around 2010. A crisis in supply-demand balance is likely to emerge within 12 years as the impact of the growing demand of the developing economies competes with the high demand from developed countries for a dwindling supply [1].

In spite of the problems and concerns explained above, nowadays the majority of the world electricity is still generated by hydropower, fossil fuels and nuclear power. Instead of using conventional energy sources, which are neither renewable nor environmentally friendly besides the increasing costs, alternative energy resources such as wind, solar, geothermal, biomass and hydrogen energy should be used. The renewable energy sources share of total world energy consumption is expected to rise from 7 percent to 8 percent by 2030 [2].

Wind energy is widely used in modern electrical systems either as stand-alone applications or utility connected power stations. In many applications the wind energy systems are combined with other renewable types such as photovoltaic (PV) and fuel cell systems. For utility-scaled sources of wind energy, a large number of wind turbines are usually built closer to form a wind-Farm. Several electricity providers today use wind farms to supply power to their remote area customers [3].

With this increased utilization of wind energy farms as a viable renewable resource it is becoming essential to improve security and the reliability of wind power systems. For standalone wind energy schemes, serious voltage instability and loss of induction generator excitation, requiring shutdown and restarting, are usually byproducts of load excursion and severe changes as well as wind speed conditions. Conventional passive capacitor compensation device becomes ineffective when the wind energy and electric load vary randomly [4].

II. SYSTEM DESCRIPTION

A Standalone Wind Energy Conversion Scheme (WECS) using induction generator (IG) is studied in this paper under a time sequence of Load Excursions and Wind variations. The standalone WECS connected to the local load bus over a radial transmission line comprising the following main components, as shown in Fig. 1.

- Wind turbine
- Gear box
- Step up and step down transformers

- Distribution power lines
- Induction generator
- Stabilization interface scheme and stabilization
- controller
- The hybrid electric load.

Each component of the proposed WECS shown in Fig. 1 is modeled in Matlab/Simulink [5] environment. The hybrid composite linear, nonlinear and motorized loads are shown in Fig. 2.

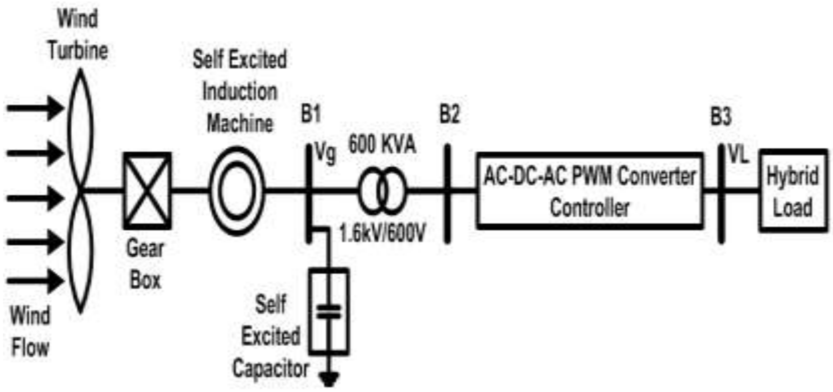


Figure 1. Sample study 600 kVA wind energy conversion scheme.

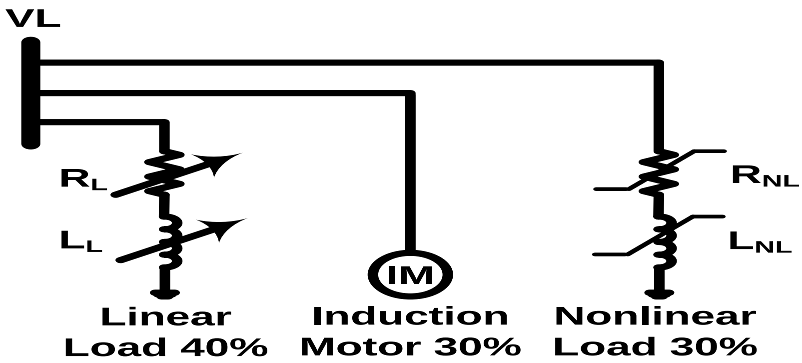


Figure 2. Hybrid composite linear, nonlinear and motorized load model.

JThe parameters of the proposed controller are selected by a guided trial and error off-line simulation to ensure the minimum induction load and generator voltage excursion for any large wind and load variation. The standalone WECS sample study system unified AC system model parameters, comprising the induction generator, wind turbine, combined hybrid load, and controller parameters are all given in Appendix. The Matlab/Simulink functional model of full AC study system is given in Fig. 3.

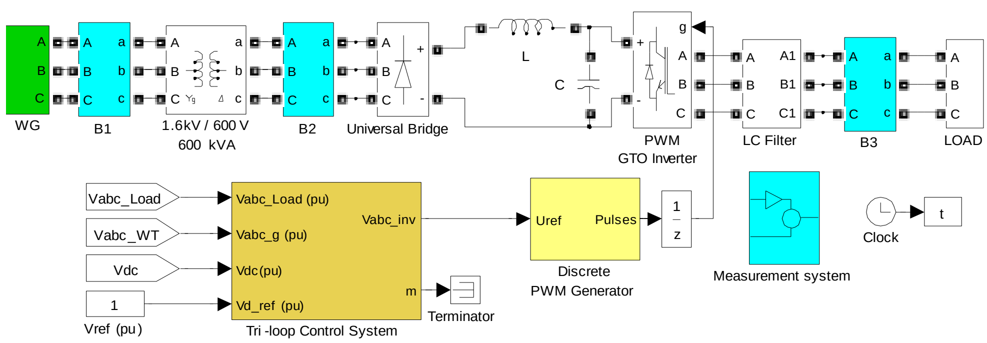


Figure 3. The Matlab/Simulink functional model of full AC study system.

The sample WECS standalone scheme was subjected to severe combined sequence of load switching/load variation/load excursion and wind speed variation and gusting. The novel tri-loop dynamic voltage tracking and FLC control scheme is shown in Fig. 4. The control signal adjusts the sinusoidal pulse width modulated IGBT six pulse inverter. The system real time dynamic response for a combined load/wind excursion time sequence as follows:

t=0.03s Linear Load excursion applied, +30%
t=0.04s Linear Load excursion removed, +30%
t=0.05s Linear Load excursion applied, -30%
t=0.06s Linear Load excursion removed, -30%
t=0.07s Wind Speed excursion applied, -30%
t=0.08s Wind Speed excursion removed, -30%
t=0.09s Wind Speed excursion applied, +30%
t=0.10s Wind Speed excursion removed, +30%

The details of the fuzzy logic control (FLC) blocks shown in Fig. 4 are discussed in [6, 7] and they are not going to be repeated here.

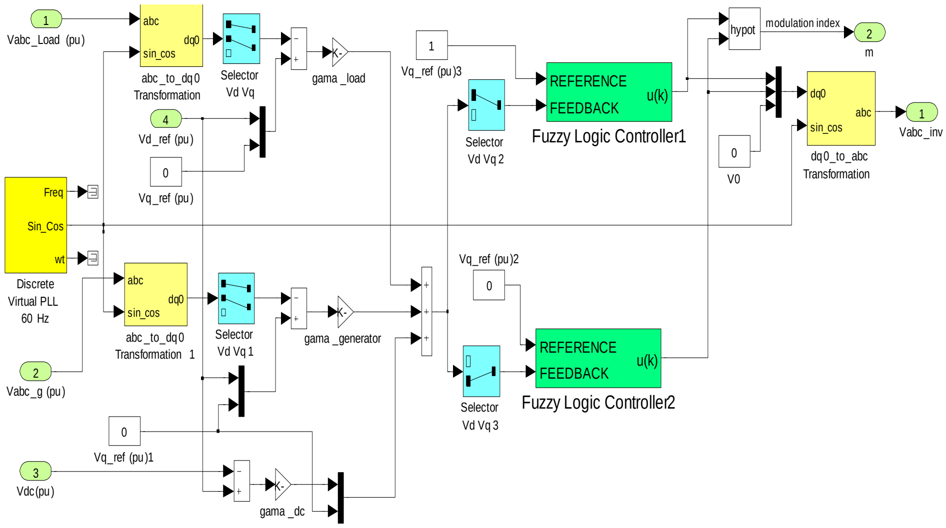
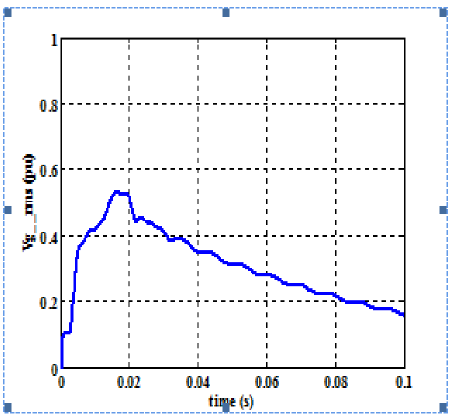
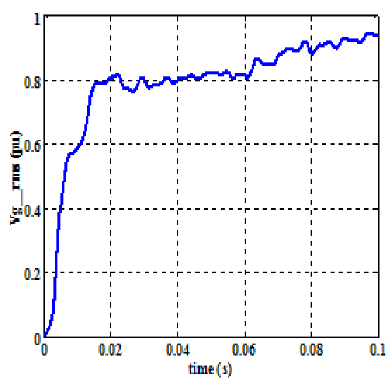


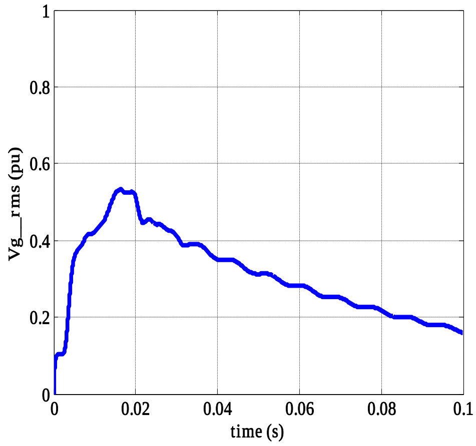
Figure 4. Dynamic tri-loop global voltage error tracking FL controlled scheme for voltage stabilization at generator, load and inverter buses.

III. SIMULATION RESULTS

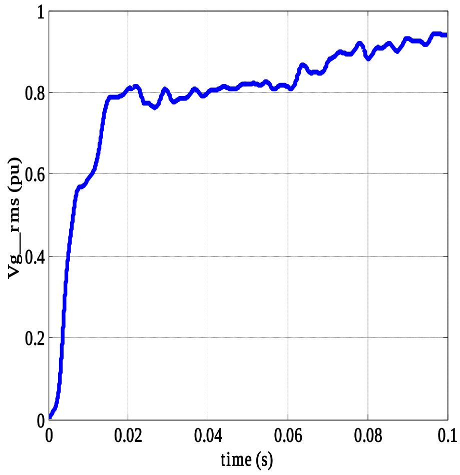
The WECS dynamic performance is compared for the two cases, with and without the AC/DC/AC PWM converter based on the novel tri-loop dynamic voltage tracking tri-loop FLC. Fig. 7 shows the system dynamic response including generator voltage (RMS), load voltage (RMS), DC-link voltage, generator current (RMS), average generator power, the voltage-current 2-dimensional phase portraits for the wind energy system controller interface system as shown in Fig. 7..



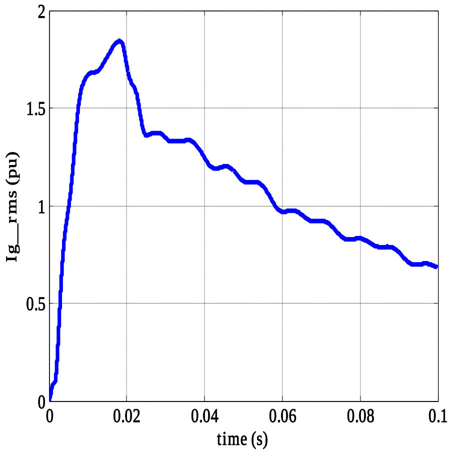




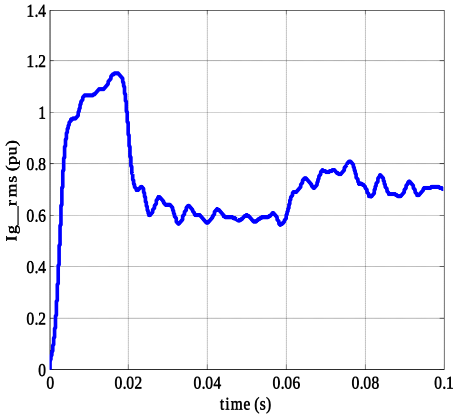
(a) RMS value of the generator voltage without SPWM converter.



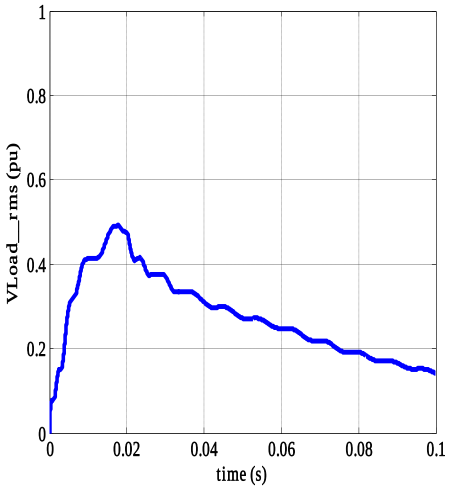
(b) RMS value of the generator voltage with the controlled SPWM converter.



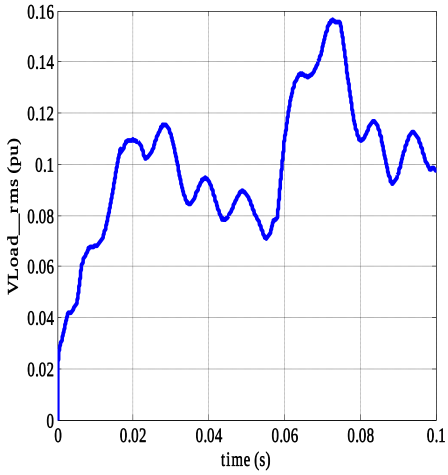
(c) RMS value of the generator current without SPWM converter.



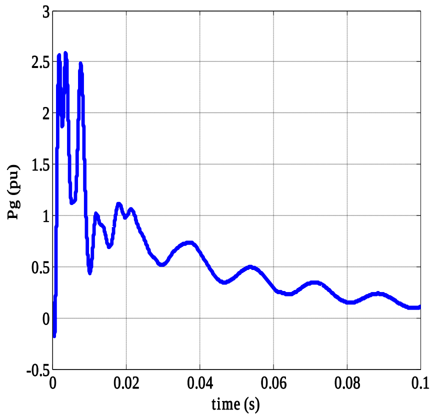
(d) RMS value of the generator current with the controlled SPWM converter.



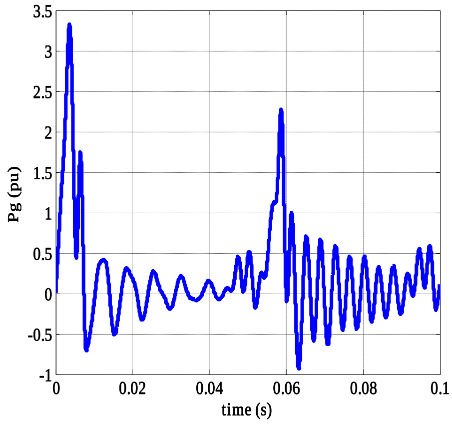
(e) RMS value of the load voltage without SPWM converter.



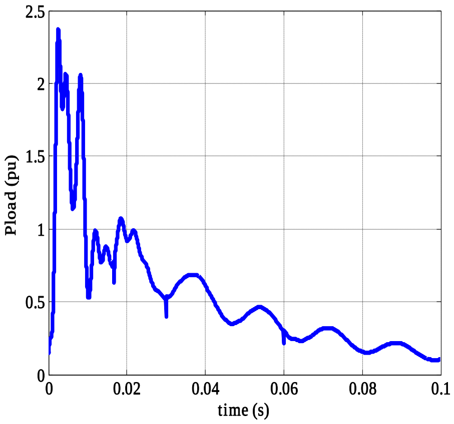
(f) RMS value of the load voltage with the controlled SPWM converter.



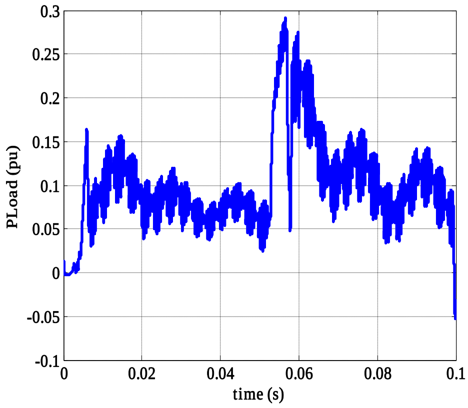
(g) Active power generated by the WECS without SPWM converter.



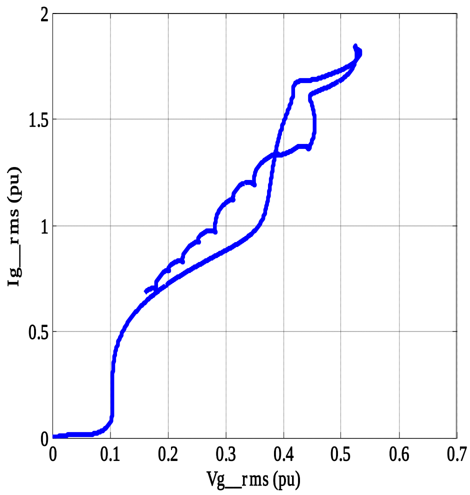
(h) Active power generated by the WECS with the controlled SPWM converter.



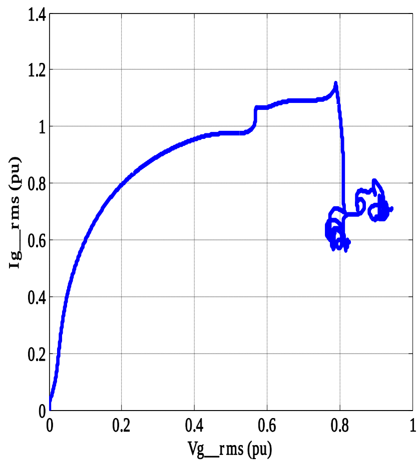
(i) Active power dissipated by the load without SPWM converter.



(j) Active power dissipated by the load with the controlled SPWM converter.



(k) RMS current-voltage trajectory at generator terminals without
SPWM converter.



(l) RMS current-voltage trajectory at generator terminals with SPWM converter.

Figure 5. WECS performance without and with the SPWM converter for a combined excursion sequence.

V. CONCLUSION

The paper presents a novel low cost dynamic voltage error tri-loop fuzzy logic controller and sinusoidal PWM driven IGBT inverter scheme for stand alone wind energy system. This PWM power converter scheme is extremely effective in ensuring voltage stabilization and enhancing power/energy utilization under severe load and wind prime mover/wind velocity excursion. A tri-loop dynamic error driven Fuzzy Logic Controller is designed and employed in this application. The use of tri-loop dynamic error signal to the controller ensures that all changes, excursions or variations in WECS, in Loads, and in DC interface system are included in the controller.

VI. APPENDIX

A.1 Simple Wind Turbine Model (Quasi-static model)

$$T_W = \frac{1}{2\lambda}\rho ARC_P V_W^2 = \frac{1}{2\omega_W}\rho AC_P V_W^3 = k\frac{V_W^3}{\omega_W}$$

Where

ρ is the specified density of air (1.25kg/m^2)

A is the area swept by the blades

R is the radius of the rotor blades

C_P is power conversion coefficient

λ is the tip speed ratio

ω_W is the wind turbine velocity in rpm

k is equivalent coefficient in per unit (0.745)

A.2 Induction Generator

3 phase, 2 pairs of poles, V_g=1.6 kV (L-L), Sg=600 KVA, Cself=150uF/Phase

$R_s = 0.016, L_{ls} = 0.06, R_r^{'} = 0.015, L_{lr}^{'} = 0.06$

$L_m = 3.5, H = 2, F = 0, p = 2$

A.3 Combined Hybrid AC Load model (@ V=1.0 pu)

A.3.1 Linear PQ Load (40%)

$P_L = 0.4pu, Q_L = 0.4pu$

A.3.2 Nonlinear (Voltage-dependent type) PQ Load (30%)

$$P = P_o(\frac{V_g}{V_{go}})^\alpha, Q = Q_o(\frac{V_g}{V_{go}})^\alpha$$

$P_o = 0.3pu, Q_o = 0.3pu, V_{go} = 1.0pu,$

$\alpha = 2-3, \beta = 2-3(Nonlinearity\ \ order)$

A.3.3 Three phase squirrel cage induction motor inrush type PQ load (30%)

Power: $S_M = 0.3pu$

Stator resistance and leakage inductance: $R_s = 0.0201pu, L_{ls} = 0.0349pu$

Rotor resistance and leakage inductance:

$R_r = 0.0377pu, L_{lr} = 0.0349pu$

Magnetizing inductance: $L_m = 1.2082pu$

Pole pairs: 2

A.4 Per unit base values used

S_{base}=600KVA, V_{base}=1.6kV (L-L)

A.5 DC-link RLC filter parameters
$R_f = 0.1\Omega, L_f = 0.2mH, C_f = 5000uF$

A.6 Weight factors
$\gamma_{vg} = 10, \gamma_{vdc} = 10, \gamma_{vload} = 0.1$

A.7. SPWM switching frequency
$f_{sw} = 2kHz$, 6 *pulse IGBT operation*

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